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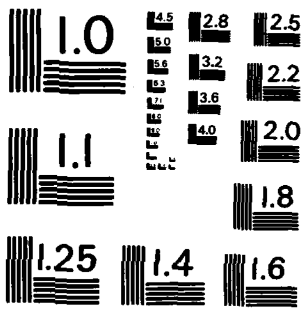

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MECHANICAL ENGINEERING NOTE 388

COCKPIT TEMPERATURES AND COOLING REQUIREMENTS OF A PARKED AIRCRAFT

by

NEIL J. REPACHOLI

and

BRIAN REBBECHI

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SUMMARY

This report investigates the cockpit and metal surface temperatures of a parked Sabre aircraft exposed to high air temperatures and solar radiation loads. Results were obtained both with and without cooling air supplied to the cockpit; these results have been used to formulate a mathematical model of the cockpit heat balance.

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16. ABSTRACT

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A

CONTENTS

NOMENCLATURE

A	Cockpit wall area (m^2)
C_p	Specific heat of air (kJ/kg)
h_c	External skin convective heat transfer coefficient ($W/m^2 \cdot °C$)
h_r	Linearised thermal radiation heat transfer coefficient ($W/m^2 \cdot °C$)
h_w	Cockpit wall heat transfer coefficient (cabin air–external skin surface) ($W/m^2 \cdot °C$)
m_f	Cooling air mass flow (g/sec)
OAT	Outside air temperature (°C)
Q_c	Heat removed by cooling air (W)
Q_e	Avionics heating load (W)
Q_s	Solar radiation transmitted through transparencies (W)
Q_w	Heat transfer through cockpit walls into cabin (W)
T_a	Outside air temperature (°C)
T_{bg}	Temperature of a 150 mm black globe (°C)
T_e	Effective mean temperature of air surrounding crew (°C)
T_{in}	Cooling air inlet temperature (°C)
T_{out}	Cooling air temperature at outlet from cockpit (°C)
T_s	Fuselage external skin temperature (°C)
WBGT	Wet bulb globe temperature (°C)
δT_{sky}	Differential between ambient temperature and effective sky temperature (°C)

1. INTRODUCTION

High temperatures attained by a parked aircraft exposed to high air temperatures and solar radiation loads are of interest for several reasons:

(*a*) the effect on crew performance of high cockpit temperatures;

(*b*) the difficulty of servicing aircraft components with high temperatures;

(*c*) the deteriorating effect on rubber seals, etc.

The cabin environment is of particular interest because aircrew are frequently required to spend long periods, in a state of combat readiness, in an aircraft prior to take-off; high cabin temperatures cause dehydration and heat stress. Whilst heat balance models for aircraft in flight have been formulated (Hughes 1968), there are no experimental evaluations known to the authors, of the cabin heat loads on a parked fighter aircraft.

This report describes tests which were carried out to measure skin temperatures (wings and fuselage), and temperatures within the cockpit, of a parked Sabre Mk 31 aircraft. Measurements were recorded during the summer period in Melbourne. The aircraft was exposed to full solar radiation, but cockpit conditions were varied by utilising both cooling air and external overhead shading.

From these results a heat balance model of the cabin has been formulated to enable prediction of the cabin environmental conditions.

2. TEST SCHEDULE AND EQUIPMENT

The test aircraft was a North American Sabre Mk 31 (Figure 1). The aircraft was parked on a concrete surface, close to a large hanger. Because of the proximity of buildings, the winds generally were unsteady and of varying direction. No shading of the aircraft was afforded by the buildings other than in the early morning. The test programme was undertaken in two distinct stages with a considerable time lapse between them. These stages were as follows:

(*a*) The aircraft was parked and exposed to direct solar radiation with the canopy closed. The aircraft and surroundings were instrumented for temperature, radiation and air velocity measurements. Temperatures on the aircraft were measured at the locations shown in Figure 2, and listed in detail in Appendix 1.

(*b*) The aircraft was parked and either shaded with no ventilation (Fig. 3), or supplied with cooling air in the shaded and unshaded configurations.

A simpler data recording system was used for the latter tests (*b*), as the equipment used in the first series of tests (*a*) was no longer available. Air temperatures for series (*b*) tests were measured at four locations in the cockpit, and cooling air mass flow, outside air temperature, wind speed and direction were recorded. High pressure air was supplied to the existing aircraft cold air unit (a turbofan system) which then supplied cooling air through the existing distribution system. Cooling air mass flow was approximately 0·1 kg/s; the cabin inlet air temperature was maintained above 0 C to obviate freezing of condensed water.

3. TEST RESULTS AND DISCUSSION

3.1 Cockpit Temperatures with Canopy Closed and Unshaded

Full details of the test results for the aircraft parked with the canopy closed and unshaded, are given in Appendix 2. Figure 4 shows a typical graph of incident solar radiation for a cloudless day. Examples of several of the temperatures from Table 2.2 (Appendix 2) are given in Table 1.

TABLE 1

Cockpit Temperatures in a Non-ventilated, Unshaded Aircraft

Position	Time	
	1200 h	1500 h
Ejector frame headrest	64°C	78°C
Footwell, stbd side	41°C	54°C
150 mm black globe at head level*	49°C	58°C
Outside air temperature	26°C	30°C

* The black globe temperature is measured at the centre of a thin copper sphere, with a matt black surface.

As indicated by Table 1, the metal temperatures (ejector frame headrest) can be very high, particularly after the aircraft has been heat-soaking for some time. At 1200 h the ejector frame was 38°C above outside air temperature; at 1500 h it was 48°C above outside air temperature. The influence of heat-soaking can also be seen in the differential between the black globe temperature (upper cockpit region) and the footwell air temperature; at 1200 h this differential was 8°C, decreasing to 4°C at 1500 h.

3.2 Cockpit Temperatures with Canopy Closed and Externally Shaded

Cockpit temperatures of the shaded aircraft with closed canopy (Fig. 3) were taken just prior to supplying cooling air to the cockpit. Just one reading per day was taken, usually after 1200 h; the aircraft having been shaded since early morning. The results are given in Table 2, and are also compared here with the earlier results (Appendix 2) for the unshaded aircraft. These tests emphasise the obvious advantage of external shading, cockpit black globe temperatures being up to 23°C lower than for the unshaded state.

TABLE 2

Effect of External Shade on Cockpit Temperatures

Position	Aircraft shaded, cockpit unventilated		Aircraft not shaded, cockpit unventilated	
	26.3.79	29.3.79	16.3.79	20.3.79
Head level	25·5°C	30·0°C	42·0°C	47·0°C
Cockpit rear	26·0°C	31·0°C	36·0°C	40·0°C
150 mm black globe	27·5°C	30·0°C	48·0°C	53·0°C
Outside air temperature	28·5°C	29·0°C	27·5°C	29·0°C

3.3 Cockpit Temperatures and Cooling Requirements with Cooling Air Supplied

The complete results for the tests with cooling air are recorded in Appendix 3; Tables 3.1 and 3.2 apply to the unshaded aircraft, and Tables 3.3 and 3.4 to the shaded aircraft. These results are summarised graphically in Figures 5 to 8, where temperatures and cooling effects are plotted against time.

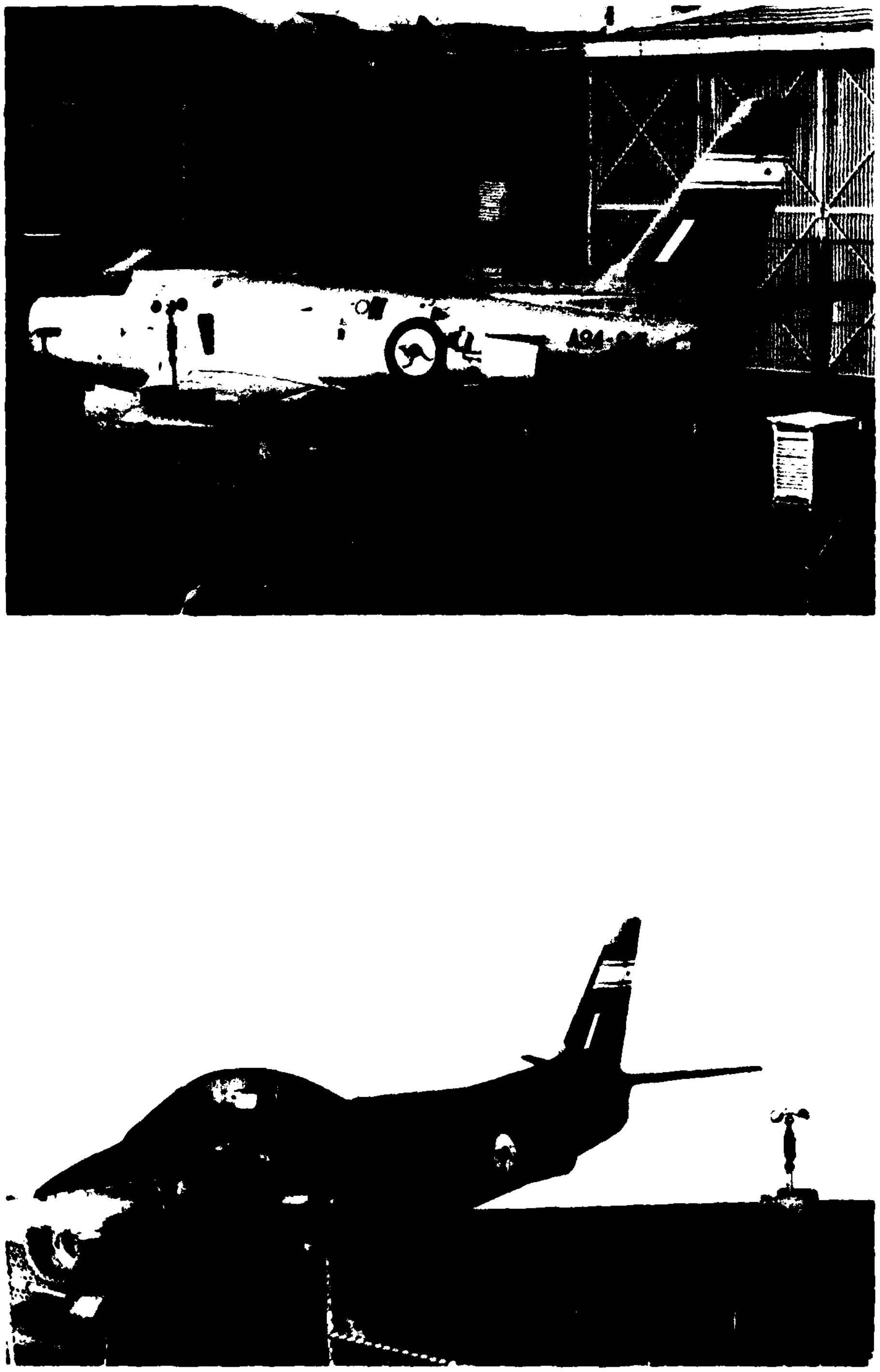

FIG. 1 TWO VIEWS OF THE INSTRUMENTED TEST AIRCRAFT –
NORTH AMERICAN SABRE MK 31

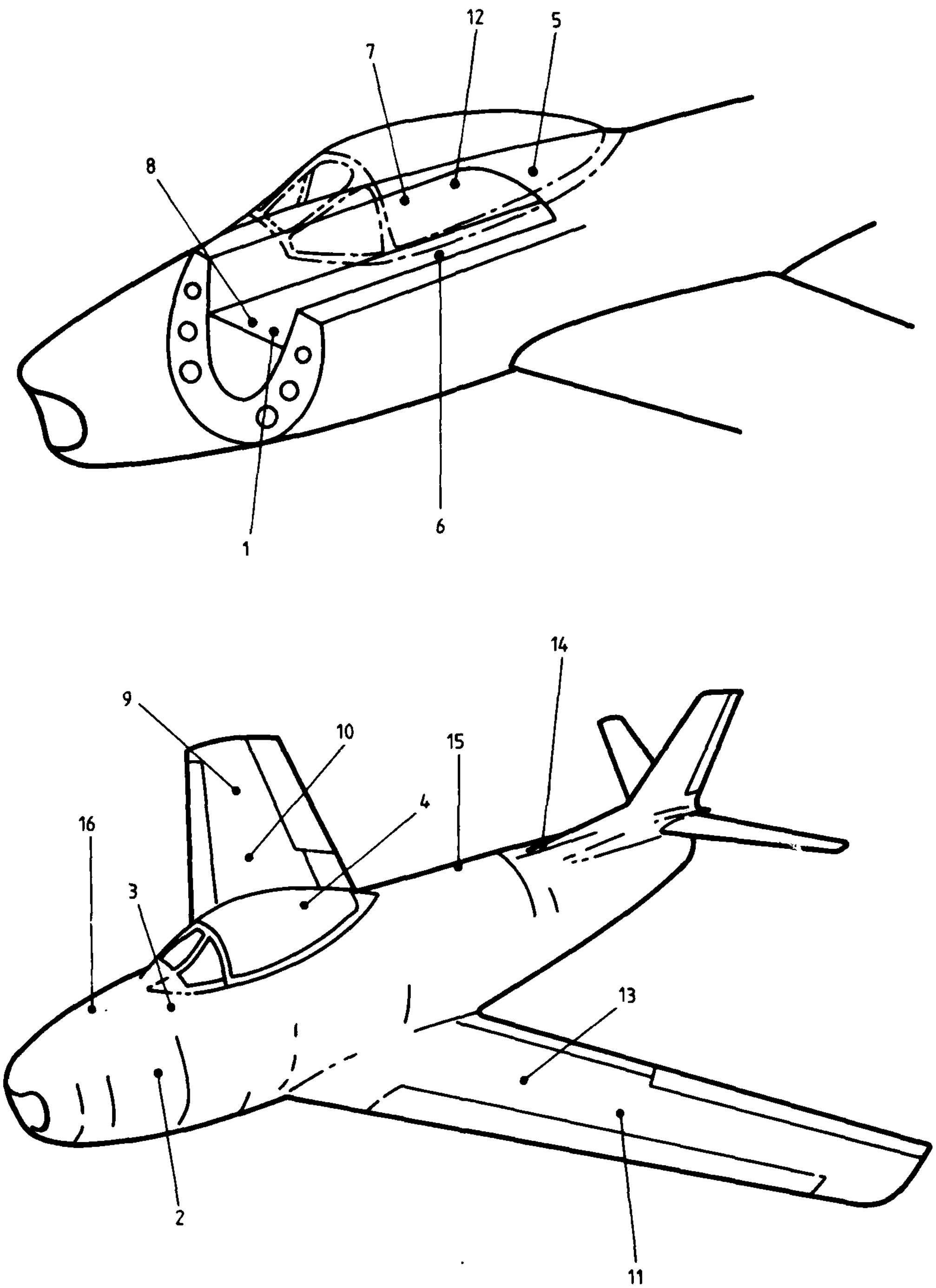

FIG. 2 TEMPERATURE SENSOR LOCATIONS ON AIRCRAFT
(SEE APPENDIX 1 FOR DETAILS OF
TEMPERATURE SENSOR LOCATIONS)

FIG. 3 TEST AIRCRAFT WITH CANOPY SHADING

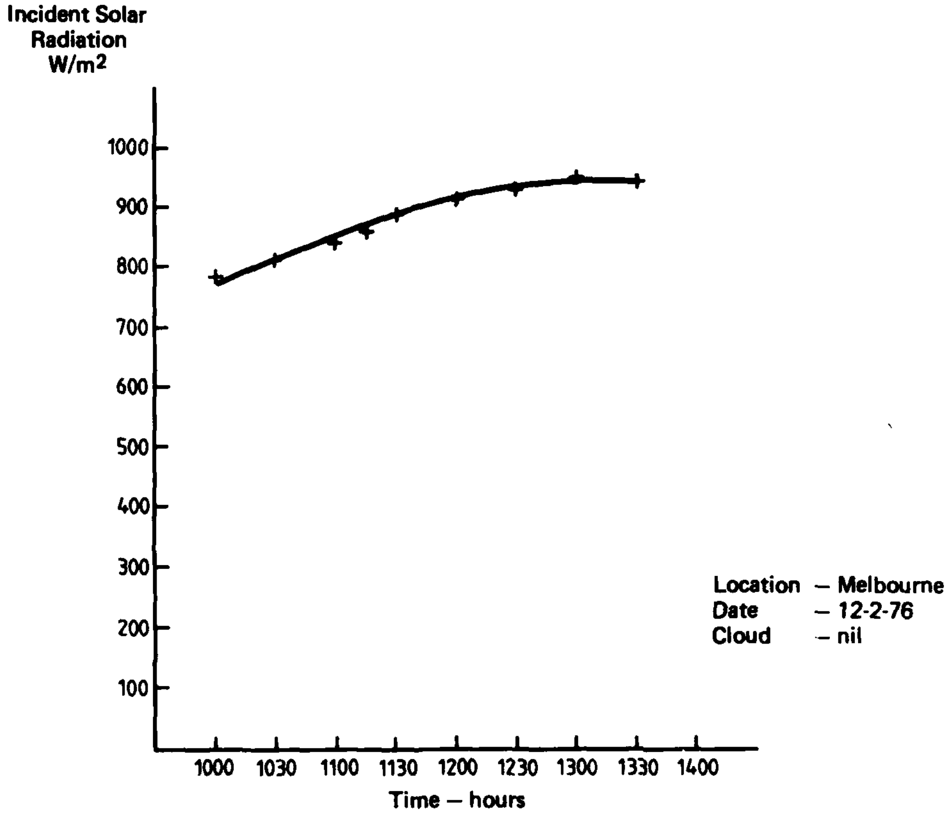

FIG. 4 INCIDENT SOLAR RADIATION MEASURED BY SOLARIMETER

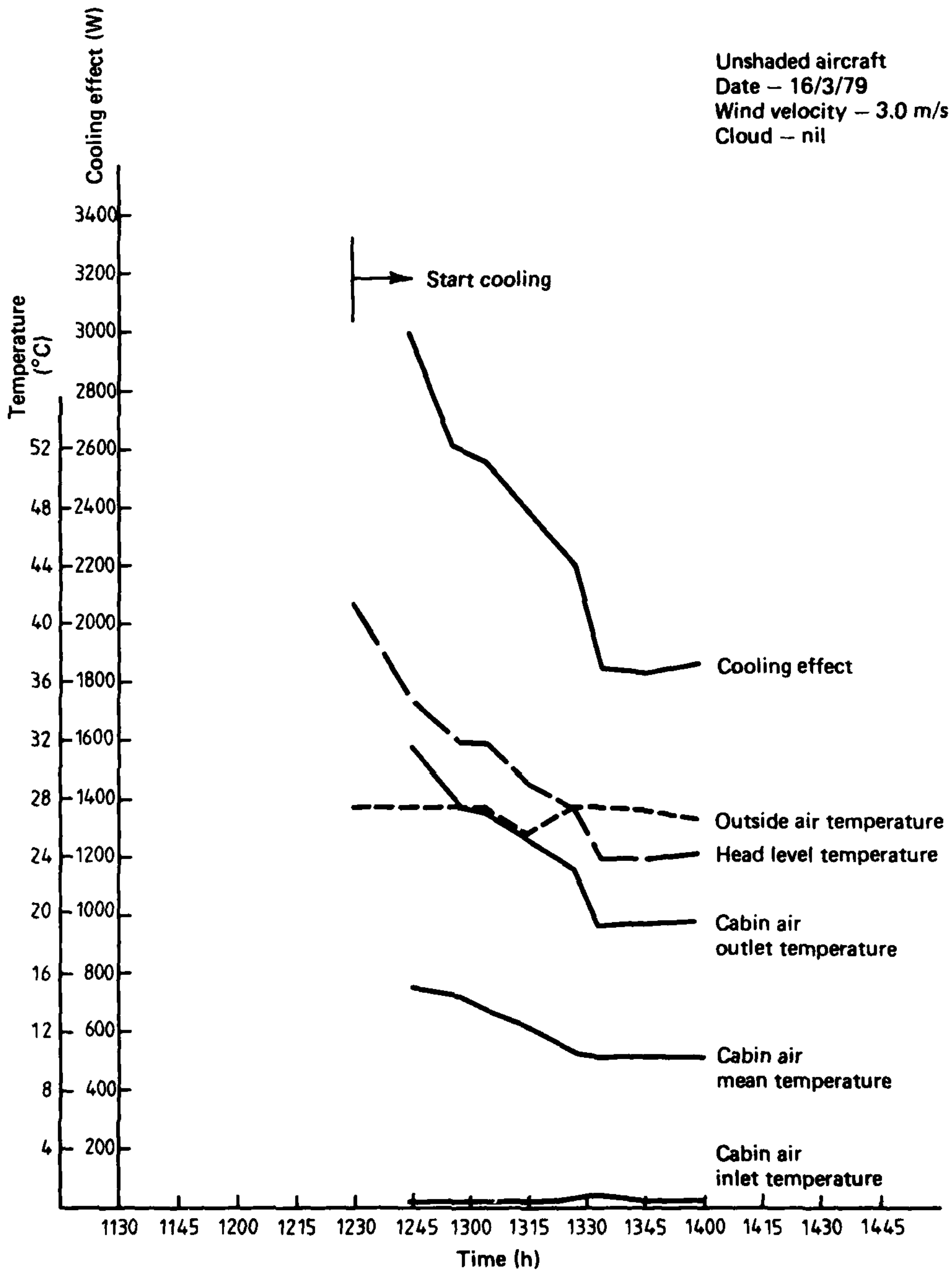

FIG. 5 COCKPIT TEMPERATURES AND COOLING EFFECT FOR AN UNSHADED AIRCRAFT

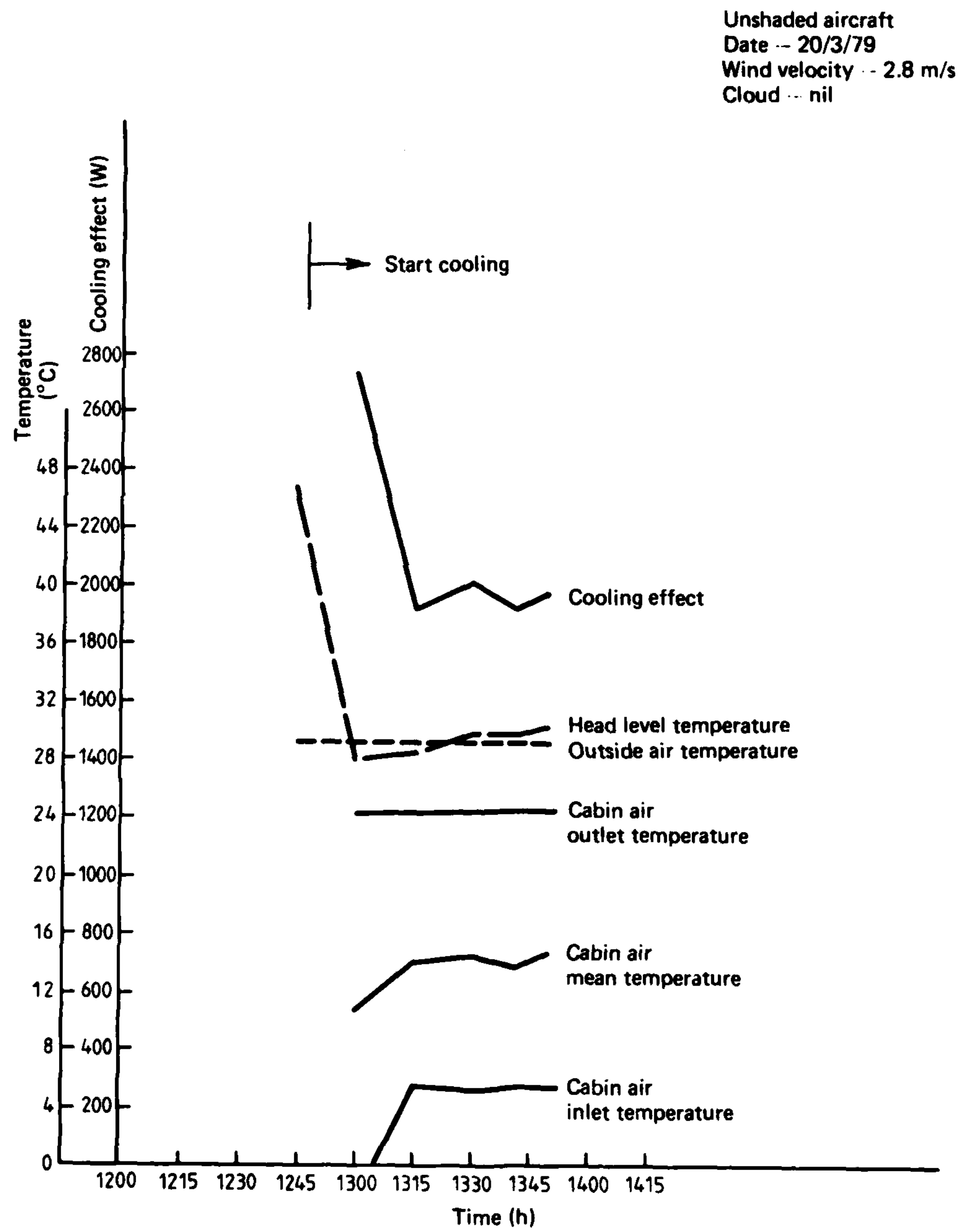

FIG. 6 COCKPIT TEMPERATURES AND COOLING EFFECT FOR AN UNSHADED AIRCRAFT

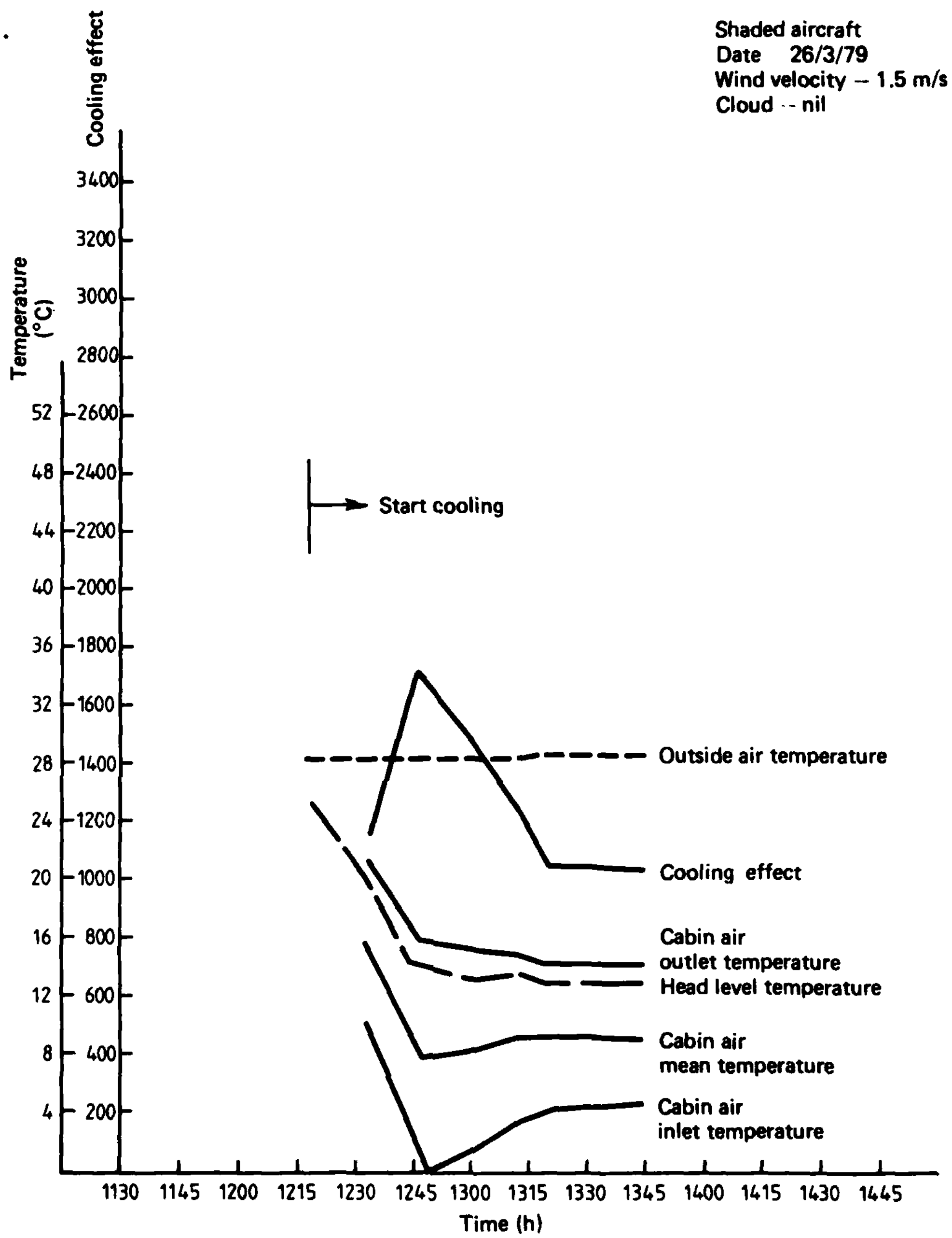

FIG. 7 COCKPIT TEMPERATURES AND COOLING EFFECT FOR A SHADED AIRCRAFT

Shaded aircraft
Date – 29/3/79
Wind velocity - 2.5 m/s
Cloud – 2/10

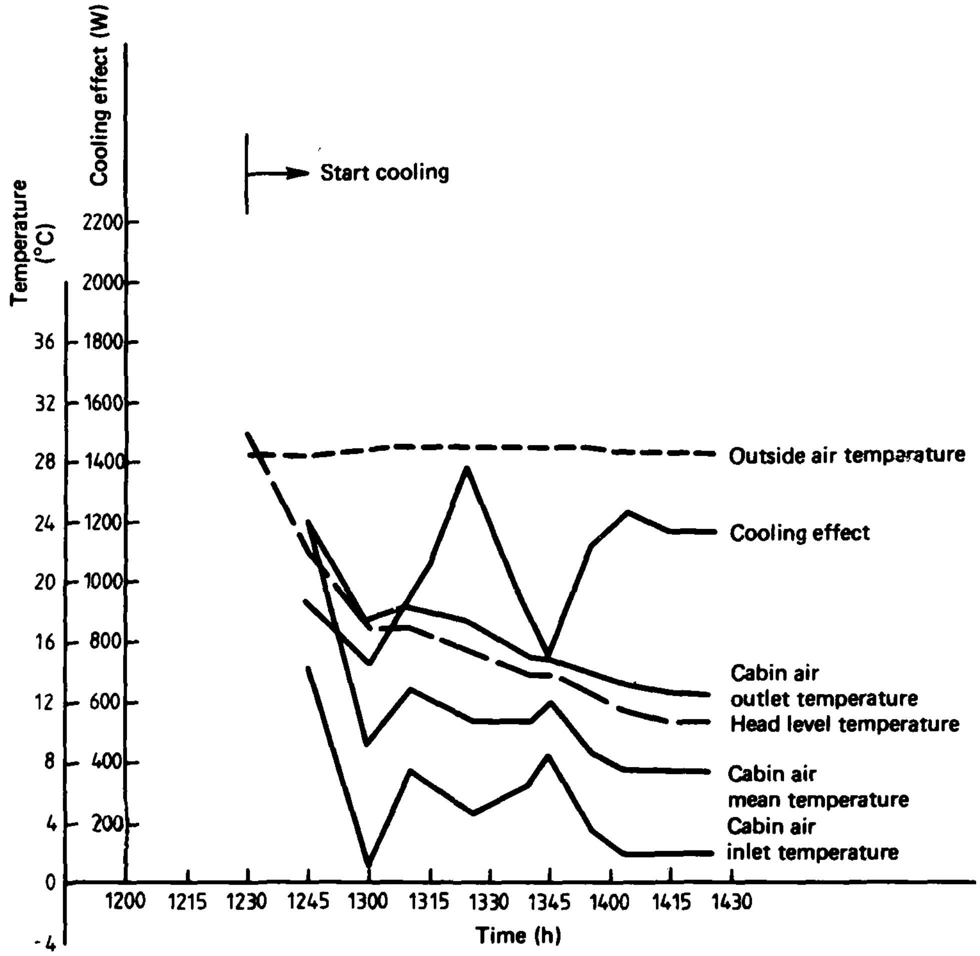

FIG. 8 COCKPIT TEMPERATURES AND COOLING EFFECT FOR A SHADED AIRCRAFT

The time taken for cabin temperatures to stabilise after the introduction of cooling air, varied from 0·5 h with external shading, to 1·0 h for the unshaded cockpit. The steady-state cabin cooling requirement without external shade was 1·87 kW (outside air temperature 27 C, mean cockpit air temperature 9·7°C). For the shaded case the cooling requirement decreased to 1·04 kW (outside air temperature 29°C, mean cockpit air temperature 9·4°C).

3.4 Summary of Experimental Results

As these tests were carried out only in Melbourne the results would be more extreme in the hotter climates of Australia. However, even with moderate outside air temperatures in the region of 30°C, the cockpit air temperatures attained would degrade crew performance. A summary of results, given in Table 3, shows the obvious benefits gained by supplying cooling air and shading the cabin area.

TABLE 3

Cooling Requirements and Cockpit Temperatures of a Shaded and Unshaded Aircraft

Comments	Stabilised cooling requirement (kW)	Outside air temperature (°C)	Black globe temperature (°C)	Head region cockpit temperature (°C)	Wind speed (m/s)
No cooling air, unshaded	—	30·0	57·0	51·0*	0·1
	—	20·0	41·0	35·0*	0·6
Cooling air, unshaded	1·87	27·0	30·5	24·5*	3·0
	1·95	29·0	36·0	30·0*	2·8
Cooling air, shaded	1·04	29·0	14·2	14·2†	1·5
	1·18	29·0	13·0	13·0†	2·5

* Taken as 6°C less than black globe temperature (after Rebbechi 1980).

† Taken as equal to black globe temperature (aircraft shaded).

4. HEAT BALANCE FOR THE COCKPIT OF A PARKED AIRCRAFT

The cockpit heat balance equation for a parked aircraft can be expressed by:

$$Q_c = Q_w + Q_s, \qquad (1)$$

where Q_c = heat removed by cooling air (W),

Q_w = heat transfer through cockpit walls into cabin (W),

Q_s = solar radiation transmitted through transparencies (W).

Also,

$$Q_w = Ah_w(T_s - T_m), \qquad (2)$$

where T_s = fuselage external skin temperature (°C),

T_m = cockpit mean air temperature (°C),

A = cockpit wall area (m²),

h_w = cockpit wall heat transfer coefficient (cabin-air to external skin surface) (W/m²·°C).

and

$$Q_w = Ah_c(T_a - T_s) + Ah_r(T_a + \delta T_{sky} - T_s). \tag{3}$$

where h_c = external skin convective heat transfer coefficient (W/m²·°C),

T_a = outside air temperature (°C),

h_r = linearised thermal radiation heat transfer coefficient* (W/m²·°C),

δT_{sky} = difference between ambient temperature and effective sky temperature (°C).

Equations (2) and (3) refer to the heat balance of the fuselage skin surface: the effect of solar heating of the fuselage skin is neglected, as the projected area of the fuselage side is very small when the sun is overhead.

Combining Equations (2) and (3) to eliminate T_s results in:

$$Q_w = Ah_w[(h_c + h_r)(T_a - T_m) + \delta T_{sky}h_r]/[h_c + h_r + h_w] \tag{4}$$

The results of aircraft tests with cooling air (Appendix 3) are summarised in Table 4.

TABLE 4

Summary of Cooled-cockpit Tests

Date	Test conditions	Outside air temperature (°C)	Mean cabin temperature (°C)	Cooling requirement (kW)	Wind velocity (m/s)
16.3.79	Unshaded, no cloud	27·0	9·7	1·85	3·0
20.3.79	Unshaded, no cloud	29·0	14·9	1·95	2·8
26.3.79	Shaded, no cloud	29·0	9·4	1·03	1·5
29.3.79	Shaded, no cloud	29·0	7·5	1·18	2·5

The external convective heat transfer coefficient h_c, as a function of wind speed, can be found from Figure 9. The heat transfer coefficient h_w can be evaluated from the shaded aircraft test results, noting that because of canopy shading, δT_{sky} is taken to be equal to zero. The cockpit wall area (including transparencies) in direct contact with the outside air is 4·64 m² (Conway and Jenkins 1951). To evaluate Q_s, the following procedure is used:

(i) Find h_w from an analysis of the results for a *shaded* aircraft, where $Q_s \equiv 0$. Hence $Q_c = Q_w$ (Equation (1)), and h_w can then be evaluated by Equation (4).

(ii) Substitute the mean value of h_w found by (i) above, into Equation (4) using now the results for an *unshaded* aircraft, noting that for a clear sky, $\delta T_{sky} = -12$ °C (Duffie and Beckman 1974). The value of Q_w then found is substituted into Equation (1) to evaluate Q_s.

The resulting values of h_w and Q_s are given in Table 5.

* Radiation exchange between surfaces properly depends on the fourth power of the absolute temperatures of the surfaces; however, where the temperature differences are small, a first power radiation coefficient has an accuracy comparable with the other quantities such as h_c.

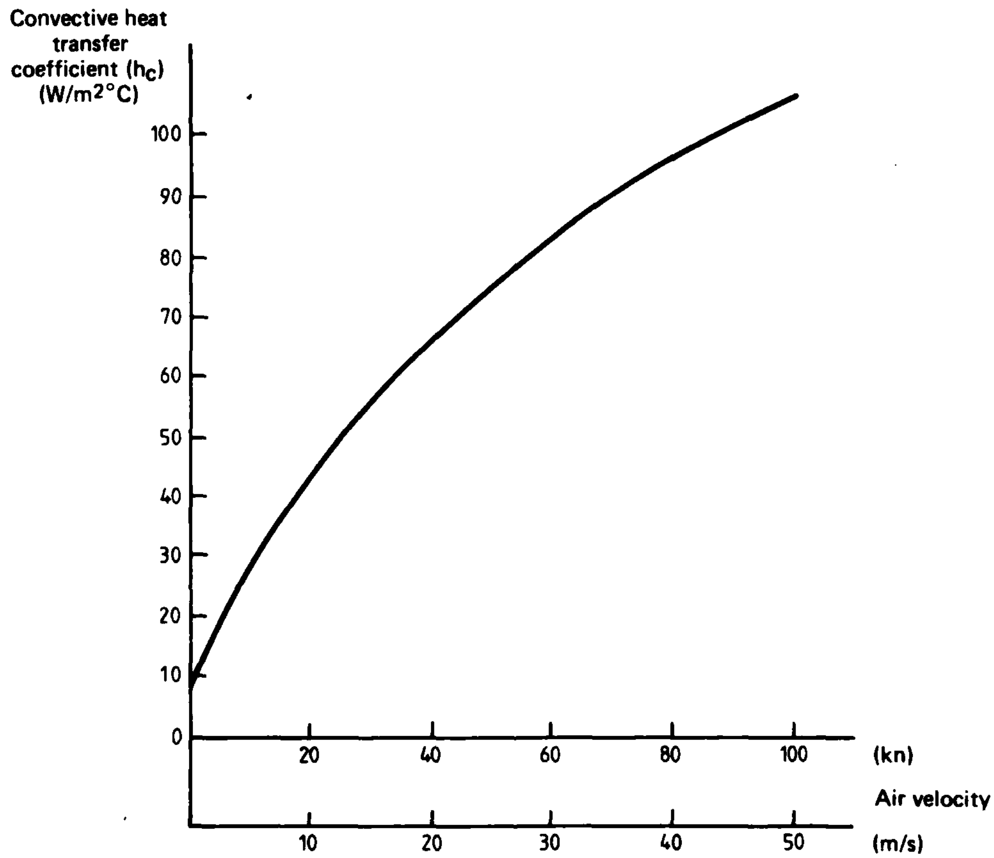

FIG. 9 CONVECTIVE HEAT TRANSFER COEFFICIENT VS AIR VELOCITY
(From Torgeson et al (1955), and Barnes and O'Brien (1970))

TABLE 5

Results for h_w and Q_s

Test conditions	Date	h_w (W/m²·°C)	Q_s (W)
Unshaded, no cloud	16.3.79		1050
Unshaded, no cloud	20.3.79		1300
Shaded, no cloud	26.3.79	26·0	
Shaded, no cloud	29.3.79	22·0	
Averaged values		24·0	1180

Substitution of these results into Equation (1) then gives:

$$Q_c = 4{\cdot}64\, h_w[(T_a - T_m)(h_c + h_r) + \delta T_{sky} h_r]/[h_c + h_r + h_w] + 1180. \tag{5}$$

Using then the values $h_m = 24{\cdot}0$ W/m²·°C (Table 5), $h_r = 6{\cdot}0$ W/m²·°C (linearised radiation exchange coefficient for temperatures in the region of 30°C), and $h_c = 20$ W/m²·°C (a function of wind speed—Fig. 9), Equation (5) can now be simplified for cloudless day, aircraft unshaded, light wind (3 m/s) conditions, to

$$Q_c = 57{\cdot}9(T_a - T_m) + 1020. \tag{6}$$

For an optimum air distribution scheme, it has been stated by Hughes (1968) that the effective mean temperature, T_e, of the air immediately surrounding the crew, is given by

$$T_e - T_{in} = 0{\cdot}75(T_{out} - T_{in}), \tag{7}$$

where T_{in} = cooling air inlet temperature (°C),

T_{out} = cooling air temperature at outlet from the cockpit (°C).

For the Sabre cockpit test, however, T_e was most likely higher than the value given by Equation (7). Insufficient measurements of cockpit temperature were taken to establish an accurate value for T_e; however, the results in Appendix 4 show that the head level temperatures are greater than the outlet temperatures. This indicates a very poor air distribution, probably because the side outlets (located at chest level) were closed for these tests, and only one inlet (located in the forward part of the cockpit) was fitted for admission of cooling air. The assumption will be made here that, for the Sabre cockpit, with side outlets open, T_e will be equal to T_{out}.
Then, as

$$T_m = 0{\cdot}5(T_{in} + T_{out}), \tag{8}$$

and

$$Q_c = m_f C_p(T_{out} - T_{in}), \tag{9}$$

where m_f = cooling air mass flow (g/s),

C_p = specific heat of air (kJ/kg),

and combining Equations (6), (8), and (9), and noting that $C_p \simeq 1{\cdot}0$ kJ/kg,

$$T_{out} = [57{\cdot}9T_a + T_{in}(m_f - 29{\cdot}0) + 1020]/[m_f + 29{\cdot}0]. \tag{10}$$

If $T_e = T_{out}$ we then have a solution for the crew air temperature, as a function of outside air temperature, cooling air inlet temperature, and mass flow. Equation (10) applies to an unshaded aircraft parked in full solar radiation, with light winds.

The cabin heat balance analysis undertaken here is considerably simplified, since no account has been taken of factors such as the variation in fuselage conductivity between canopy walls. The validity of this analysis is restricted then to similar conditions to those encountered during the tests described. This is a reasonable limitation, for if cooling is to be provided for a parked aircraft, then the design of the cooling system would be required to cope with the worst conditions, namely full solar radiation, and high outside air temperatures.

5. DISCUSSION

5.1 The Uncooled Aircraft

As would be expected, very high cabin temperatures were reached with the canopy completely closed. Black globe temperatures of 60 C and ejector frame temperatures of 76 C were recorded for an outside air tempeature of 29 C.

Such high temperatures would rapidly lead to heat stress of the aircrew. For the 1% extreme* high humidity levels encountered in Australia of 0·025 kg moisture/kg dry air (see Rebbechi 1980), and an OAT of 29 C, the cockpit WBGT† would be 41·5 C. This high WBGT would certainly cause a very rapid decrement in mental and perceptual performance, eventually causing collapse of the aircrew. That high temperature levels are encountered in this situation is not a recent discovery, as shown by the study of the effects of cabin temperatures on pilot performance in RAAF fighter aircraft, by Cameron and Cumming (1963).

However, there now exists general agreement that a WBGT of greater than 28 C will result in a decrement in crew performance (see, for example, Hendy and Clark 1979). For an aircraft parked in full solar radiation, this WBGT would be exceeded in the cockpit of an uncooled aircraft even for the relatively *cold* outside air temperature of 15 C.‡

During all of these tests the canopy was completely closed. Opening the canopy could be expected to bring about a reduction in cockpit temperature. Harrison and Higenbottam (1977), in comparative tests on a parked, uncooled aircraft, found that the cockpit temperature, with the canopy partially open, depended on wind direction. When the wind was blowing in a longitudinal direction, the cockpit black globe temperature exceeded the outside air temperature by 20–25 C. Thus for this unfavourable wind direction, little relief is afforded to the crew by a partial opening of the canopy.

5.2 The Cooled Aircraft

From the analysis of the cockpit heat balance of a parked Sabre aircraft it was found that the effective mean air temperature T_e, around the pilot, could be expressed by

$$T_e = [57{\cdot}9T_a + T_{in}(m_f - 29{\cdot}0) + 1020]/[m_f + 29{\cdot}0], \tag{11}$$

where T_a = outside air temperature (°C),

T_{in} = cabin inlet air temperature (°C),

m_f = cooling air mass flow (kg/s).

Equation (11) applies to the aircraft parked in full solar radiation, with the canopy closed. If an avionic heating load Q_e were also present, then Equation (11) becomes

$$T_e = [57{\cdot}9T_a + T_{in}(m_f - 29{\cdot}0) + 1020 + Q_e]/[m_f + 29{\cdot}0]. \tag{12}$$

To extrapolate Equation (12) to the uncooled aircraft case ($m_f = 0$), it is necessary to note the relationship between T_e and T_{in} (Equation (7)), where for the *uncooled* aircraft, $T_{out} = T_{in}$, and $T_e = T_{in}$. Hence, from Equation (12), substituting $m_f = 0$ and $T_e = T_{in}$,

$$T_e = T_a + 17{\cdot}6 + Q_e/58. \tag{13}$$

From this equation the cockpit black globe temperature (T_{bg}) for an *uncooled* aircraft can then be derived if it is assumed that T_{bg} is 6 C above cockpit air temperature (see footnote p. 11). From Equation (13), then, for the uncooled aircraft in the absence of cockpit avionic heating,

$$T_{bg} = T_a + 23{\cdot}6. \tag{14}$$

* The 1% extreme is that temperature (or humidity) that is equalled or surpassed for 1% of the time (7·5 h) in the most severe month.

† The Wet Bulb Globe Temperature (WBGT) is a widely used prediction of heat stress, which combines the effects of air temperature and moisture content, radiant heat loading and wind velocity on heat stress; its use is further discussed by Rebbechi (1980).

‡ Assuming saturated outside air at 15 C (moisture content 0·0105 kg/kg).

This is in general agreement with the experimental results, where black globe temperatures of between 20 and 30 C above ambient were measured.

The effect of cockpit temperatures of avionic heat loads can be considerable. For example, Equation (13) shows that an internal heat load of 1000 W would raise the cockpit temperature by 17 C. This result accords closely with that of Harrison and Higenbottam (1977).

6. CONCLUSIONS

Severe thermal stress on crew members will result from them beirg seated in the closed or nearly closed cockpit of an uncooled fighter-type aircraft. The addition of heat loads from avionic equipment in the cockpit, greatly worsens an already intolerable environment.

A heat balance of the cockpit has been formulated to facilitate computation of the cooling air requirements to bring about an acceptable cabin environment. Where cooling air supplies are not available, shading of the cockpit area is essential to minimise aircrew heat stress, and also to maintain metal temperatures at a sufficiently low level to permit servicing of the aircraft.

Although these tests were carried out on a Sabre aircraft, the results should be generally applicable to other fighter type aircraft, having overhead transparencies.

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APPENDIX 1

Aircraft Instrumentation

Position		Location
Temperature sensors	1	Footwell—port side
	2	Aircraft—near gunsight
	3	Footwell—starboard side
	4	Ejector frame—top, behind headrest
	5	Under canopy 0·6 m aft of headrest
	6	Port armrest
	7	Starboard armrest
	8	Air temperature [box with circulating fan in starboard footwell]
	9	Starboard, upper wing, outboard [2 m from fuselage]
	10	Starboard, upper wing, inboard [1 m from fuselage]
	11	Port, lower wing
	12	Black globe temperature
	13	Port, upper wing, inboard [1 m from fuselage]
	14	Upper fuselage aft [4 m from pilot]
	15	Upper fuselage aft [2 m from pilot]
	16	Upper fuselage front [matt black painted section]
Meteorological instrumentation	17	Net radiometer over aircraft wing upper surface
	18	Net radiometer over ground
	19	Wind direction (degrees)
	20	Wind speed
	21	Outside air temperature (Stephenson's Screen)

APPENDIX 2

Test Records for Uncooled Aircraft

TABLE 2.1

Temperatures and Environmental Conditions

Unshaded cockpit, no cooling air—2.2.76

No.	Parameter and position	Time (h)									
		1100	1130	1200	1230	1300	1330	1400	1430	1500	1530
	Temperatures										
1	Footwell—port side (air) (°C)	9	9	20	13	14	15	—	15	—	—
2	Aircraft—near gunsight (surface) (°C)	43	51	51	54	56	61	59	60	61	63
3	Footwell—starboard side (air) (°C)	22	27	29	35	38	40	41	40	41	41
4	Ejector frame—top, behind headrest (surface) (°C)	52	56	58	61	63	64	65	66	67	68
5	Under canopy 0·6 m aft of headrest (air) (°C)	36	39	40	42	44	45	45	45	43	42
6	Port armrest (surface) (°C)	45	48	50	50	50	51	51	52	52	48
7	Starboard armrest (surface) (°C)	33	36	40	41	45	50	54	55	56	55
8	Air temperature box [in starboard footwell] (air) (°C)	22	25	28	29	32	34	36	38	39	40
9	Starboard, upper wing, outboard (surface) (°C)	39	40	42	44	45	46	45	46	46	44
10	Starboard, upper wing, inboard (surface) (°C)	38	42	43	46	48	49	48	47	47	46
11	Port, lower wing (surface) (°C)	24	25	25	26	27	27	27	27	28	27
12	Black globe in cockpit (air) (°C)	36	39	40	41	43	44	44	45	45	45
13	Port, upper wing, inboard (surface) (°C)	32	38	41	43	45	47	48	47	48	47
14	Upper fuselage, 3 m aft of pilot (surface) (°C)	35	36	37	39	40	41	42	42	42	41
15	Upper fuselage 2 m aft of pilot (surface) (°C)	36	36	36	37	40	39	36	39	39	38
16	Upper fuselage, front (surface) (°C)	47	49	52	57	58	61	61	61	61	60
	Radiation										
17	Net radiation [aircraft] (W/m²)	690	750	750	750	810	810	810	810	810	750
18	Net radiation [ground] (W/m²)	570	570	630	630	630	630	690	690	690	630
19	*Wind direction* (θ°)	Varying between 160° and 180°									
20	*Wind speed* (m/s)	0·45	0·06	0·02	0·25	0·20	0·06	0·02	0·00	0·06	0·06
	Temperature										
21	Outside air temperature (°C)	14	14	16	14	14	17	19	20	20	21

TABLE 2.2

Temperatures and Environmental Conditions

Unshaded cockpit, no cooling air—7.2.76

No.	Parameter and position	Time (h)									
		1100	1130	1200	1230	1300	1330	1400	1430	1500	1530
	Temperatures										
1	Footwell—port side (air) (°C)	35	38	38	40	40	42	46	48	50	51
2	Aircraft—near gunsight (surface) (°C)	52	57	58	62	65	69	73	73	73	74
3	Footwell—starboard side (air) (°C)	36	39	41	44	46	49	51	—	54	54
4	Ejector frame—top, behind headrest (surface) (°C)	57	60	64	68	70	73	76	—	78	78
5	Under canopy 0·6 m aft of headrest (air) (°C)	43	46	49	54	57	59	62	—	58	55
6	Port armrest (surface) (°C)	51	56	60	62	62	64	65	—	65	61
7	Starboard armrest (surface) (°C)	37	41	45	48	52	58	63	—	66	65
8	Air temperature box [in starboard footwell] (air) (°C)	28	30	34	36	39	40	44	—	47	50
9	Starboard, upper wing, outboard (surface) (°C)	42	46	48	50	53	56	59	55	57	55
10	Starboard, upper wing, inboard (surface) (°C)	46	50	51	55	57	59	63	61	58	56
11	Port, lower wing (surface) (°C)	30	33	34	36	37	39	40	40	39	38
12	Black globe in cockpit (air) (°C)	43	46	49	52	55	57	60	60	58	56
13	Port, upper wing, inboard (surface) (°C)	37	41	45	51	54	58	61	60	59	57
14	Upper fuselage 3 m aft of pilot (surface) (°C)	41	44	47	50	53	55	60	59	56	55
15	Upper fuselage 2 m aft of pilot (surface) (°C)	39	43	45	48	51	52	57	56	56	52
16	Upper fuselage, front (surface) (°C)	49	53	56	60	64	67	71	75	75	74
	Radiation										
17	Net radiation [aircraft] (W/m²)	720	780	780	840	840	780	780	780	780	780
18	Net radiation [ground] (W/m²)	480	480	540	540	540	540	480	480	480	480
19	*Wind direction* (θ°)	Varying between 180° and 270°									
20	*Wind speed* (m/s)	0·5	0·67	0·72	0·15	0·15	0·11	0·05	0·75	0·55	0·54
	Temperatures										
21	Outside air temperature (°C)	23	25	26	27	29	30	29	31	30	31

TABLE 2.3

Temperatures and Environmental Conditions

Unshaded cockpit, no cooling air—11.2.76

No.	Parameter and position	Time (h)									
		1100	1130	1200	1230	1300	1330	1400	1430	1500	1530
	Temperatures										
1	Footwell—port side (air) (°C)	14	18	18	26	30	33	35	36	36	37
2	Aircraft—near gunsight (surface) (°C)	42	49	48	50	49	56	56	57	54	56
3	Footwell—starboard side (air) (°C)	32	34	36	38	40	40	41	41	41	41
4	Ejector frame—top, behind headrest (surface) (°C)	46	51	54	57	57	60	62	64	64	65
5	Under canopy 0·6 m aft of headrest (air) (°C)	30	34	35	38	38	39	37	38	38	36
6	Port arm rest (surface) (°C)	41	47	48	50	47	51	51	51	47	46
7	Starboard armrest (surface) (°C)	33	36	38	42	45	49	51	51	51	52
8	Air temperature box [in starboard footwell] (air) (°C)	25	26	28	30	32	33	35	36	37	37
9	Starboard, upper wing, outboard (surface) (°C)	33	36	37	41	38	40	42	42	40	39
10	Starboard, upper wing, inboard (surface) (°C)	34	40	41	43	40	43	44	44	43	41
11	Port, lower wing (surface) (°C)	23	25	26	27	27	27	27	28	28	27
12	Black globe in cockpit (air)	30	35	37	40	39	41	41	41	40	39
13	Port, upper wing, inboard (surface) (°C)	30	36	37	41	38	42	44	43	42	42
14	Upper fuselage 3 m aft of pilot (surface) (°C)	31	35	35	38	35	39	39	40	39	39
15	Upper fuselage 2 m aft of pilot (surface) (°C)	31	37	36	38	33	38	39	39	37	37
16	Upper fuselage, front (surface) (°C)	43	53	51	56	43	58	59	59	56	56
	Radiation										
17	Net radiation [aircraft] (W/m²)	390	930	210	930	390	870	810	810	750	750
18	Net radiation [ground] (W/m²)	270	690	390	600	210	630	570	510	510	510
19	*Wind direction* (θ°)	Varying between 290° and 345°									
20	*Wind speed* (m/s)	0·55	0·1	0·9	0·6	0·4	0·7	0·54	0·85	0·9	1·05
	Temperature										
21	Outside air temperature (°C)	17	17	18	18	19	19	20	21	20	19

APPENDIX 3

Test Records for a Cooled Aircraft

TABLE 3.1

Temperature and Environmental Conditions

Unshaded cockpit with cooling air—16.3.79

Measurements	Time (h)								
	1230	1240	1255	1305	1315	1325	1335	1345	1355
Cockpit conditions									
Inlet air temp. (°C)	—	0·0	0·0	0·0	0·0	0·0	−0·5	0·0	0·0
Outlet air temp. (°C)	—	31·5	27·5	27·0	25·0	23·0	19·0	19·0	19·5
Black globe temp. (°C)	48·0	41·0	38·0	38·0	35·0	33·5	30·0	30·0	30·5
Head level temp. (est.*) (°C)	42·0	35·0	32·0	32·0	29·0	27·5	24·0	24·0	24·5
Air mass flow (g/s)	—	94	94	94	95	95	95	95	95
Cooling effect† (W)	—	2990	2610	2563	2398	2206	1871	1823	1871
Environmental conditions									
Outside air temp. (°C)	27·5	27·8	27·4	26·0	27·5	27·5	27·5	27·8	27·0
Wind direction (°θ)	210								
Wind speed (m/s)	3·0								

* Head level temperature is estimated by subtracting 6°C from black globe temperature.

† Cooling effect = $m_f C_p (T_{out} - T_{in})$, where $C_p = 1{\cdot}01$ kJ/kg.

TABLE 3.2

Temperature and Environmental Conditions

Unshaded cockpit with cooling air—20.3.79

Measurements	Time (h)					
	1245	1300	1315	1330	1340	1350
Cockpit conditions						
Inlet air temp. (°C)	—	−3·0	5·5	4·5	5·0	5·0
Outlet air temp. (°C)	—	24·0	24·5	24·5	24·5	24·8
Black globe temp. (°C)	53·0	34·0	34·5	35·5	35·5	36·0
Head level temp. (est.*) (°C)	47·0	28·0	28·5	29·5	29·5	30·0
Air mass flow (g/s)	—	100	100	100	100	100
Cooling effect† (W)	—	2720	1910	2000	1910	1990
Environmental conditions						
Outside air temp. (°C)	29·0	29·0	29·0	29·0	29·0	29·0
Wind direction (θ°)	330					
Wind speed (m/s)	2·8					

* Head level temperature is estimated by subtracting 6°C from black globe temperature.

† Cooling effect = $m_f C_p (T_{out} - T_{in})$, where $C_p = 1{\cdot}01$ kJ/kg.

TABLE 3.3

Temperature and Environmental Conditions

Shaded cockpit with cooling air—26.3.79

Measurements	Time (h)							
	1250	1305	1320	1330	1340	1350	1400	1410
Cockpit conditions								
Inlet air temp. (°C)	—	10·5	0	1·5	3·5	4·5	4·5	4·5
Outlet air temp. (°C)	—	21·5	16·0	15·5	15·0	14·5	14·5	14·2
Black globe air temp. (°C)	27·5	22·0	16·0	15·0	15·0	14·5	14·5	14·2
Head level temp. (°C)	25·5	20·5	14·5	13·5	14·0	13·0	13·0	13·0
Air mass flow (g/s)	—	106	106	105	105	105	105	106
Cooling effect† (W)	—	1070	1710	1490	1220	1060	1060	1040
Environmental conditions								
Outside air temp. (°C)	28·5	28·5	28·5	28·5	28·5	28·5	29·0	29·0
Wind direction (θ)	350							
Wind speed (m/s)	1·5							

TABLE 3.4

Temperature and Environmental Conditions

Shaded cockpit with cooling air—29.3.79

Measurements	Time (h)										
	1230	1245	1300	1310	1320	1340	1345	1355	1405	1415	1425
Cockpit conditions											
Inlet air temp. (°C)	—	14·5	1·0	7·5	4·5	6·5	8·5	3·5	2·0	2·0	2·0
Outlet air temp. (°C)	—	24·0	17·5	18·5	17·5	15·5	15·5	14·0	13·5	13·0	13·0
Black globe temp. (°C)	30·0	24·0	18·5	18·5	17·5	15·5	15·5	14·0	13·5	13·0	13·0
Head level temp. (°C)	30·0	22·5	17·0	17·5	15·5	14·0	14·0	12·5	11·5	11·0	11·0
Air mass flow (g/s)	—	96	96	96	107	107	107	107	107	107	107
Cooling effect† (W)	—	940	704	1070	1400	970	754	1130	1240	1190	1190
Environmental conditions											
Outside air temp. (°C)	28·5	28·5	29·0	29·0	29·0	29·0	29·5	29·5	29·0	29·0	29·0
Wind direction (θ)	340										
Wind speed (m/s)	2·5										

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